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INVESTIGATION ON THE EFFECT OF PREPARATORY FINISHING AND RESIN TREATMENT ON THE TEAR STRENGTH OF VARIOUS COMMERCIAL COTTON FABRICS

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

INVESTIGATION ON THE EFFECT OF PREPARATORY FINISHING PROCESSES AND RESIN TREATMENT ON THE TEAR STRENGTH OF VARIOUS COMMERCIAL COTTON FABRICS[1]

by

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INTRODUCTION

The tear strength of cotton textiles is of major importance in most types of apparel textiles. It is generally stated that the tear strength of resin-treated fabrics is substantially lower than that for untreated fabrics. Recognizing that any means that will significantly increase the tear strength of cotton fabrics will increase the utilization of cotton, the United States Department of Agriculture has instituted a research project at the Fabric Research Laboratories, Inc., aimed at improving the tear strength of cotton fabrics with particular emphasis on fabrics intended for resin treatment. In addition, a part of this research is concerned with the improvement of tear of heavy weight (4 to 7 ozs.) outer wear apparel textile fabrics, which are finished with materials that impart permanent desirable creases and pleats.

The overall plan for conducting this research program calls for an analytical determination on the cause of loss in tear strength due to resin treatments; theoretical determination of modification of fabric properties to obtain optimum tear strength; design, construction, and evaluation of experimental fabrics to determine the validity of theoretical determinations; and, the resin treatment of experimental fabrics and comparison of tear resistance with commercial counterparts.

Part I of the subject contract requires that an analysis be made of treated and untreated commercially available cotton fabrics, classed as light and heavy weight apparel textiles, to determine the cause of loss in tear strength due to resin treatment. Accordingly, 10 sets of treated and untreated cotton fabrics representing a wide range of weights, constructions, and finishes were obtained from commercial sources for the purposes of Part I of the subject contract.

TEST METHODS AND RESULTS

THE TONGUE-TEAR TEST

Description of Test

In the tongue-tear test as performed in this investigation, a specimen 8 inches long and 3

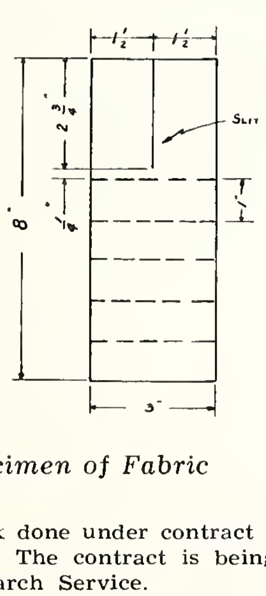

Figure 1.—*Specimen of Fabric*

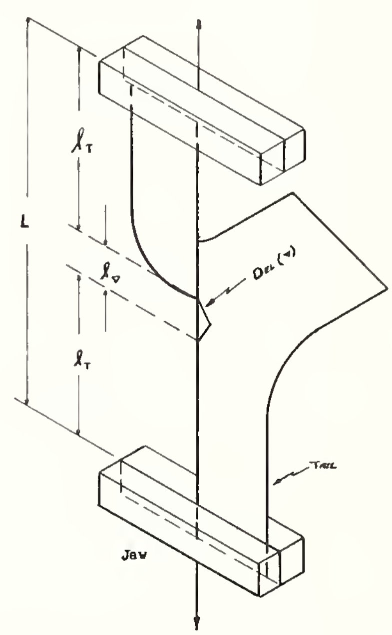

Figure 2.—*Fabric in Jaws of Tensile Tester*

[1] A report of work done under contract with the U. S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract is being supervised by the Southern Utilization Research and Development Division of the Agricultural Research Service.

inches wide was cut as shown in Figure 1. The dotted horizontal lines represent lines drawn 1 inch apart on the fabric. This specimen was then placed in the jaws of a tensile tester so that one-half of the slit section was placed in the top jaw and one-half in the lower jaw, as shown in Figure 2.

The lower jaw was then moved downward at a constant speed. A strip chart recorder, with an indicating system capable of traversing the 10 inch of chart in 1 second, recorded the load transmitted to the upper jaw.

As the tear reached each of the horizontal 1 inch marks, the pen, which records the load, was pipped on the chart to mark the end of 1 inch of tear.

The actual load-measuring system consisted of a bonded strain gage-type load cell with its amplifying equipment. This type of instrument, such as the Instron Tensile Tester, which was used here, is essential for proper study of tear, since the variations in load are much too fast to be measured with any of the high-inertia low-speed recording devices. Furthermore, the servo-controlled jaw speed establishes the elongation coordinate of the load-elongation diagram.

Definitions

The following definitions apply to Figure 2.

The del is the triangular shaped distortion at the active region of tearing, named (by Krook and Fox[2]) after the del operator used in vector analysis, "Δ".

L = Total jaw separation
T = Length of each tail (unextended)
Δ = Length of the del

The following definitions apply to the load-elongation diagram obtained in tear, shown in Figure 3. P_u is the upper load limit of each peak or the highest load supported before a yarn rupture. P_m is the lower load limit of each peak or the load on the jaws just after a yarn has ruptured. Δ P is the load drop resulting from the rupture of a yarn or yarns in a given peak. The average upper and lower peak loads are obtained directly from the tear test charts. In this work the averages of the upper peak loads are the load levels that have half the upper peaks above them and the other half below. The average lower peak loads were obtained in a similar manner. This technique

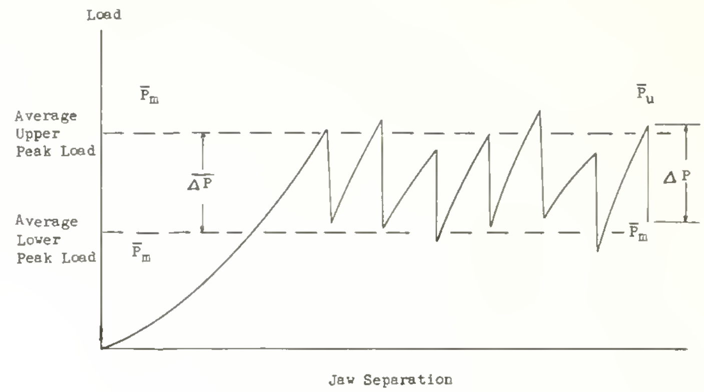

Figure 3.—*Load-Elongation Diagram of Tongue Tear Test*

has been incorporated herein in lieu of measuring the value of each peak and calculating the arithmetic mean, because it greatly reduces the time required to analyze the test charts without sacrificing in any significant way the accuracy of the estimate of the average upper or lower peak load. E is the tear energy per inch of tear, usually calculated for the third inch of tear.

$$E \quad \frac{\bar{P}u + \bar{P}m}{2} \quad \Delta L$$

where ΔL is the amount of jaw movement during the particular inch of tear for which the energy is being calculated. In this work, tear energy, which is a function of the area under the loading diagram, is based on a measurement of that area by an integrator activated during the time required to tear 1 inch of test fabric. This value, when divided by the jaw travel of the crosshead on the Instron Tensile Tester, for 1 inch of tear, yields the average tear force. N is the number of peaks per inch of fabric torn.

The ravel strip tensile tests, single end yarn tests, and tongue-tear tests were made under the following conditions:

	Type of Test		
	Tongue Tear	Ravel Strip Tensile	Single Yarn Tensile
Apparatus	*Instron Tensile Tester*		
Full-scale load (lbs.)	5 & 10	100	2
Chart speed (in./min.)	20	5	5 & 10
Jaw speed (in./min.).	2	2	2
Gage length (in.)	3	3	0.5 & 10

[2] Krook and Fox, "Study of Tongue Tear Test," T.R.J. 15, 389-402 (1945).

Table 1.—*Summary of finished fabric constructions*

Sample number	Fabric weight (oz./sq.yd.)	Threads/Inch Warp	Threads/Inch Filling	Fabric type	Finishing treatment
1	3.29	85	76	Print cloth	Wash-and-wear.
2	3.77	85	80	do.	Embossed waffle pique.
3	3.19	85	74	do.	Glazed chintz.
4	3.23	81	83	do.	U.F. [1] and softener.
5	4.31	143	51	Poplin	U.F. and softener.
6	3.30	139	69	Broadcloth	U.F., E.F. [2] and softener.
7	6.35	130	54	Sateen	Resin treatment.
8	8.31	116	55	Twill	do.
9	3.99	54	49	Chambray	do.
10	4.96	61	53	Plaid	do.

[1] U.F.—Urea formaldehyde.
[2] E.F.—Dimethylol ethyleneurea.

Percent yarn crimp measurements were obtained on the yarns used in the single end tensile tests made at the 10-inch gage length. Ten inch gage marks were first made on the yarns in the fabric state. When the yarns were removed from the fabric, the gage marks on the yarns were then placed in the nip of the jaws of the Instron Tensile Tester. The magnitude of crimp in the yarn was then determined by extrapolating the Hookean portion of the load elongation curve to the zero load axis, and the length represented by the distance from the origin of the test to the intersection of the extrapolated slope of the stress-strain curve and the zero load axis is considered as the crimp. This length expresed as a percentage of the 10-inch length of yarn in the fabric is the percent crimp.

There are several values available from the tongue tear test data that could serve to characterize this fabric property. At this point in the research program it was not deemed advisable to select only one criterion for tongue tear. Thus, Table 10 in the Appendix, lists four related measures of tear strength for each fabric. They are as follows:

1. Average upper peak load, $\overline{P}_u$, (lbs.)
2. Average lower peak load, $\overline{P}_m$, (lbs.)
3. Average tear energy, E, (inch-lbs.)
4. Average tear force, T. F. (lbs.)

Descriptions of the finished fabric constructions of the sample fabrics investigated in Part I are summarized in Table 1. The range of fabric weights runs from 3 to 8 ozs. per square yard and the fabric textures vary from (54 x 49) to (139 x 69). These fabrics represent a diversity of fabric type and finishing treatment.

To permit detailed analysis of the tear strength characteristics exhibited by these fabrics, a series of tensile studies have been made which give different estimates of the yarn strength. The yarn strength as it lies in the fabric is approximated by dividing the average tensile strength of a 1-inch strip of fabric by the average number of threads per inch. The single end yarn strength determined in this fashion is called the "IN" fabric yarn strength. Two measurements of single end yarn strength have been made on yarns removed from fabrics in Samples 1 to 6. These tests were made at a 10-inch and one-half inch gage length. The tests conducted at the 10-inch gage length were also used to make crimp measurements.

Any analysis of the changes in tear strength of cotton fabrics that have been resin treated must take into account the effects of changes in fabric geometry (ends and picks per inch, warp and filling crimp) as well as the effects of the chemical treatments, in order to evaluate as far as possible the contribution that each makes in the tear strength of the finished goods. Thus, wherever possible a set of fabrics was examined at six stages of production. These are referred to in this work as follows:

Classification	Sample Identification
A	Greige goods
B	Desized
C	Desized and scoured
D ("prepared" goods)	Desized, scoured, bleached, and dyed
E	Resin treated finished goods
F	Same as "E" without resin

In the case of fabrics 1 to 6, the samples tested in the desized, and in the desized and scoured states (Class B and C) were made up at Fabric Research Laboratories, Inc., out of the greige goods received from the finishing plants.

The fabrics were desized with 1.5%, on the weight of the goods, of the Royce Chemical Company's Neozyme H. T.[3] at 180°-190°F., for 3 hours, then rinsed and treated with a similar formulation at 212°F. for 2 hours and given a final rinse. A liquor ratio of 30:1 was used in this laboratory desizing operation.

Half of the desized samples were then scoured with 2% NaOH, on weight of the goods, and 0.5% Tergenol[3] using a liquor to cloth ratio of 20:1. The cloth was kept immersed throughout the scour, which was made at the boil for 4 hours, and during the hot and cold water rinses.

Fabric numbers 7 and 8 were obtained at each stage of production from the finishing plant. It was not possible to obtain samples of fabrics 9 and 10 other than the prepared goods and the finished goods.

The Appendix to this report contains the following tabulations:

Table 10—A summary of the tongue-tear test data obtained on the 51 samples examined in this phase of the research.

Table 11—Fabric construction data, i. e., fabric weight, ends and picks per inch, percent yarn crimp, and crimp balance.

Table 12—Ravel strip tensile strength and percent elongation data.

Table 13—Several estimates of the single end yarn strength.

Table 14—A summary of the number of yarns breaking per load drop during the tearing action.

The information contained in these tables will be evaluated as it becomes pertinent to the discussions that follow.

DISCUSSION

The purpose of the work in this phase of the research program was "to determine the cause of the loss in tear strength due to resin treatments." However, inasmuch as a cotton fabric is subjected to three major finishing processes (desizing, scouring, bleaching, and dyeing) which alter its geometry—texture and crimp—and change the frictional characteristics of the surface of the cotton fibers, it was deemed necessary to evaluate the effect of each of these processes on its tear strength. Thus, insofar as it was possible the fabrics examined in this work have been studied at the six stages of production described in the preceding section.

The phrase, loss in tear strength, implies a prior level of tear strength to which the present magnitude of resistance to tear is compared. In this work, the percent change in tear (not all the fabrics suffer a loss in tear) is generally based on the value of the tear strength found in that stage of production which immediately precedes the one under discussion; but, in a few cases, the percent change in tear is based on the tear strength of the greige fabric. The latter is referred to as the percent total change while the former is termed the percent relative change in tear strength.

The criterion of tear strength selected for use in these evaluations of the effects on tear strength of the various manufacturing processes is the average upper peak load ($\overline{P}_u$). This parameter can be considered as the average load necessary to continue the tearing action and is therefore a suitable criterion for the present analysis.

It seemed appropriate to have the discussion paralleling the sequence of processes necessary to the production of a finished resin-treated cotton fabric. Each finishing treatment there-

[3] Use of a company and/or product named by the Department does not imply approval or recommendation of the product to the exclusion of others which may also be suitable.

Table 2.—*Summary of changes in average upper peak loads*

		Warp			Filling		
Sample Number	Stage of Production	Absolute Change (lbs.)	Relative Change (%)	Total Change (%)	Absolute Change (lbs.)	Relative Change (%)	Total Change (%)
1	A vs B	—1.06	—26.5	1-B —26.5	+.22	+10.4	1-B +10.4
	B vs C	—1.20	—40.8	C —56.5	—.96	—41.2	C —35.1
	C vs D	—.09	—5.2	D —58.8	—.07	+5.1	D —31.6
	D vs E	+.22	+13.3	E —53.3	+.28	+19.4	E —18.5
	D vs F	—.09	—5.5	F —61.0	+.14	+11.1	F —24.2
2	A vs B	—.98	—24.7	2-B —24.7	—.02	—.9	2-B —.9
	B vs C	—1.11	—37.2	C —52.8	—.79	—36.4	C —37.0
	C vs D	—.29	—15.5	D —60.1	+.15	+10.7	D —30.1
	D vs E	—.12	—7.6	E —63.1	—.53	—34.6	E —54.3
	D vs F	+.02	+1.3	F —59.6	—.05	—3.3	F —32.4
3	A vs B	—.87	—23.0	3-B —23.0	+.21	+10.3	3-B +10.3
	B vs C	—1.13	—38.7	C —52.8	—.94	—42.0	C —36.0
	C vs D	—.28	—15.6	D —60.2	+.08	+6.2	D —32.0
	D vs E	—.23	—15.2	E —66.3	—.49	—35.5	E —56.2
	D vs F	—.03	—2.0	F —61.0	+.22	+15.9	F —21.2
4	A vs B	—.64	—20.7	4-B —20.7	—.06	—2.0	4-B —2.0
	B vs C	—1.09	—44.5	C —56.0	—1.18	—40.7	C —41.9
	C vs D	+.08	+5.9	D —53.0	—.02	—1.2	D —42.6
	D vs E	+.24	+16.7	E —45.5	—.08	—4.7	E —45.3
	D vs F	—.01	—.7	F —53.7	—.06	—3.5	F —44.6
5	A vs B	+.34	+7.0	5-B +7.0	+.27	+4.8	5-B +4.8
	B vs C	—2.64	—51.0	C —47.5	—3.45	—59.1	C —57.1
	C vs D	—.25	—9.8	D —52.7	+.20	+8.4	D —53.5
	D vs E	+.63	+27.5	E —39.7	----------	----------	E ----------
	D vs F	+.04	+1.7	F —51.9	+.02	+.8	F —53.1
6	A vs B	+.20	+4.6	6-B +4.6	+.09	+3.7	6-B +3.7
	B vs C	—2.59	—56.8	C —54.8	—1.18	—46.6	C —44.6
	C vs D	—.10	—.5	D —51.5	+.05	+3.7	D —42.6
	D vs E	----------	----------	E ----------	+.56	+40.0	E —19.6
7	A vs B	----------	----------	7-B ----------	+1.20	+22.2	7-B +22.2
	B vs C	—3.28	—36.7	C —36.7	—2.53	—38.3	C —24.6
	C vs D	—.53	—9.4	D —42.7	+0.86	+21.1	D —8.7
	D vs E	----------	----------	E ----------	—1.30	—26.4	E —32.8
	D vs F	+2.51	+49.0	F —14.5	+1.29	+26.2	F +15.2
8	A vs B	----------	----------	8-B ----------	+.01	+0.2	8-B +0.2
	B vs C	----------	----------	C ----------	—1.75	—31.0	C —30.9
	C vs D	----------	----------	D ----------	+.67	+17.2	D —19.0
	D vs E	----------	----------	E ----------	—1.27	—27.8	E —41.5
	D vs F	----------	----------	F ----------	+1.71	+37.4	F +11.3
9	D vs E	----------	----------	9-E ----------	—5.20	—45.8	9-E —45.8

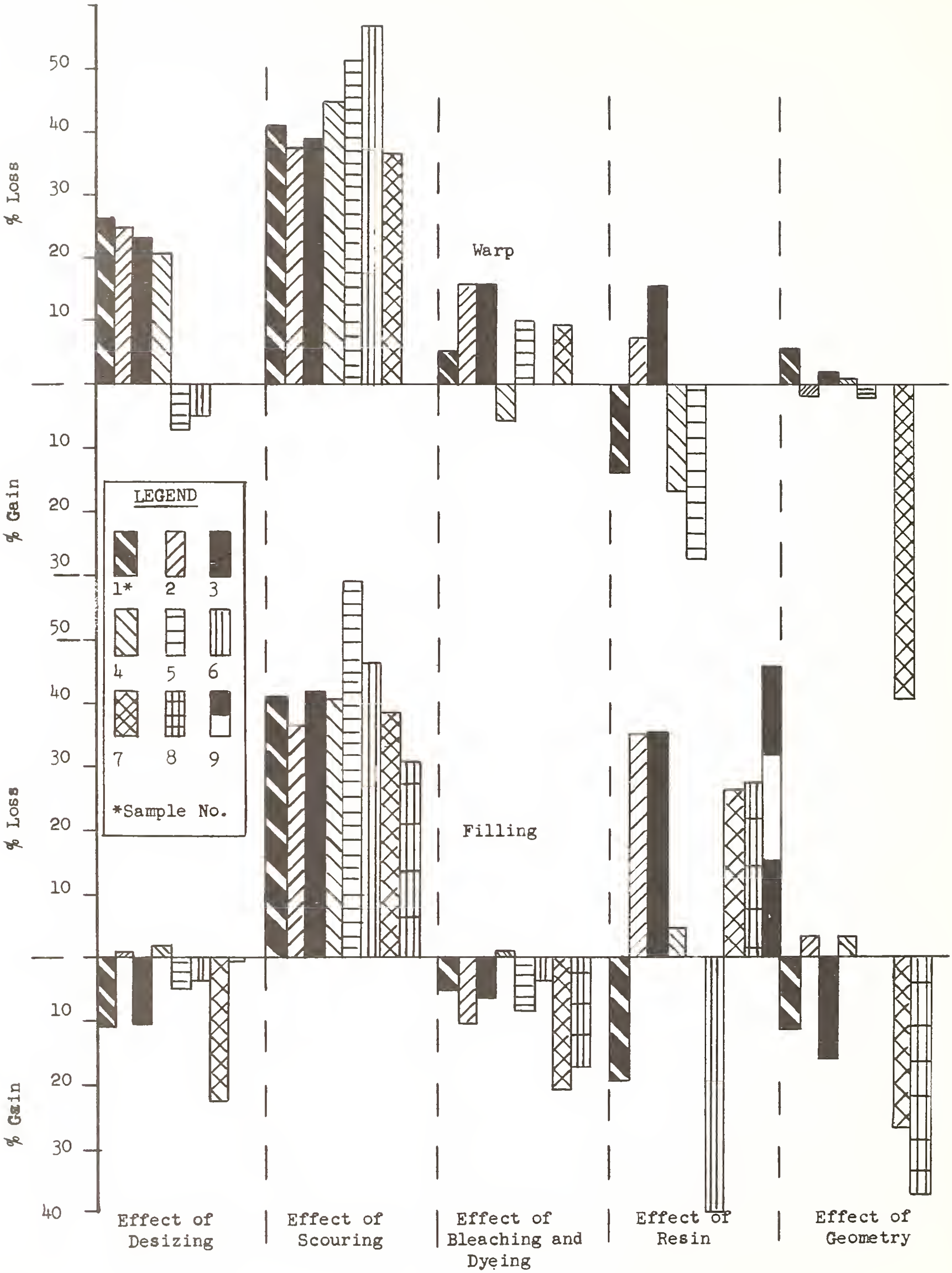

Figure 4.—*Percent relative change in tear strength at each stage of production.*

Table 3.—*Comparison of physical properties of the greige (A) and desized fabrics (B)*

Sample Classification	1		2		3		4		5		6		7		8	
	A vs	B	A vs	B	A vs	B	A vs	B	A vs	B	A vs	B	A vs	B	A vs	B
$\overline{P}_u$ - Warp	4.00	2.94	3.96	2.98	3.79	2.92	3.09	2.45	4.84	5.18	4.36	4.56	S.T.[4]	8.93	S.T.[4]	T.T.[5]
Filling	2.11	2.33	2.19	2.17	2.03	2.24	2.96	2.28	5.57	5.84	2.44	2.53	5.40	6.60	5.64	5.65
Ends/Inch	79	85	78	84	79	85	79	84	142	144	135	137	125	135	110	112
Picks/Inch	78	84	79	84	79	84	86	89	53	60	70	79	55	55	57	56
Weight (oz/yd^2)	3.73	3.77	3.72	3.83	4.03	3.73	3.41	3.53	4.70	4.90	3.75	3.86	7.25	6.73	9.26	8.36
Ravel Strip Tensile																
(lbs.) - Warp	58.1	52.7	57.2	51.1	58.1	52.4	47.4	43.1	103.2	99.5	91.2	83.2	133.6	122.8	160.4	164.0
Filling	47.4	44.5	45.8	43.1	44.5	41.7	55.3	49.6	57.8	59.7	48.7	49.4	65.2	57.9	79.8	67.8
% Elong. Warp	16.1	24.9	17.6	25.5	16.0	24.7	10.9	18.9	23.4	46.4	20.6	40.4	15.8	13.4	24.4	20.1
Filling	16.2	27.4	16.8	25.5	14.5	25.1	16.0	26.7	8.5	10.9	11.3	13.9	13.1	21.3	11.5	14.1
Yarn Strength																
IN[1] - Warp	0.74	0.62	0.73	0.61	0.74	0.62	0.60	0.51	0.73	0.69	0.67	0.61	1.07	0.91	1.46	1.46
Filling	0.61	0.53	0.58	0.51	0.56	0.50	0.64	0.56	1.09	0.99	0.70	0.63	1.18	1.05	1.40	1.21
OUT[2] - Warp	0.74	065	0.71	0.60	0.69	0.55	0.56	0.45	0.63	0.56	0.57	0.50	0.92	0.74	1.42	1.17
Filling	0.38	0.45	0.43	0.42	0.34	0.42	0.40	0.40	0.99	1.02	0.49	0.56	1.02	1.04	0.94	1.10
% Crimp - Warp	8.9	14.3	8.9	15.2	9.1	14.4	5.2	9.7	13.9	26.7	10.0	24.4	6.2	4.3	13.3	11.4
Filling	7.7	15.6	7.4	14.6	6.9	14.7	8.1	14.6	0.7	2.4	3.2	4.5	5.1	13.2	4.4	7.4
Crimp Balance	+1.16	1.09	+1.20	+1.04	+1.32	1.02	1.56	1.51	+19.85	+11.3	+3.13	+5.42	+1.22	3.06	+3.02	+1.54
Threads/Load Drop[3]																
Warp	1.74	1.55	1.54	1.60	1.62	1.59	1.58	1.44	1.93	2.28	1.99	2.46	S.T.	3.55	S.T.	T.T.
Filling	1.62	1.47	1.59	1.60	1.44	1.50	1.56	1.50	1.26	1.41	1.65	1.92	1.63	1.71	1.44	1.46

[1] 3-inch gage length in fabric.
[2] 10-inch gage length—single yarn test.
[3] Number of peaks per inch of tear divided by number of threads per inch orthoganol to directions of tear.
[4] S.T.—side tear.
[5] T.T.—tail tear.

Table 4.—*Comparison of physical properties of the desized (B) and scoured fabrics (C)*

Sample Classification	1 B	vs C	2 B	vs C	3 B	vs C	4 B	vs C	5 B	vs C	6 B	vs C	7 B	vs C	8 B	vs C
$\overline{P}_u$ - Warp	2.94	1.74	2.98	1.87	2.92	1.79	2.45	3.09	5.18	2.54	4.56	1.97	8.93	5.65	T.T.	S.T.
Filling	2.33	1.37	2.17	1.38	2.24	1.30	2.28	2.96	5.84	2.39	2.53	1.35	6.60	4.07	5.65	3.90
Ends/Inch	85	86	84	86	85	85	84	84	144	145	137	138	135	135	112	114
Picks/Inch	84	85	84	85	84	88	89	91	60	61	79	80	55	55	56	56
Weight (oz/yd²)	3.77	3.74	3.83	3.61	3.73	3.60	3.53	3.58	4.90	4.78	3.86	3.72	6.73	6.41	8.36	7.99
Ravel Strip Tensile																
(lbs.) - Warp	52.7	55.0	51.1	56.2	52.4	53.5	43.1	43.4	99.5	90.3	83.2	72.8	122.8	142.8	164.0	178.2
Filling	44.5	46.0	43.1	47.2	41.7	39.9	49.6	63.8	59.7	68.4	49.4	51.8	57.9	70.8	67.8	79.1
% Elong. Warp	24.9	24.6	25.5	25.3	24.7	25.1	18.9	19.7	46.4	41.7	40.4	38.8	13.4	14.0	20.7	18.3
Filling	27.4	27.7	25.5	25.9	25.1	26.3	26.7	27.8	10.9	11.0	13.9	12.3	21.3	22.3	14.1	16.7
Yarn Strength																
IN [1] - Warp	0.62	0.64	0.61	0.65	0.62	0.63	0.51	0.52	0.69	0.62	0.61	0.53	0.91	1.06	1.46	1.56
Filling	0.53	0.54	0.51	0.56	0.50	0.45	0.56	0.70	0.99	1.12	0.63	0.65	1.05	1.29	1.21	1.41
OUT [2] - Warp	0.65	0.52	0.60	0.64	0.55	0.61	0.45	0.54	0.56	0.65	0.50	0.54	0.74	0.88	1.17	1.44
Filling	0.45	0.51	0.42	0.48	0.42	0.39	0.40	0.63	1.02	1.21	0.56	0.61	1.04	1.29	1.10	1.43
% Crimp - Warp	14.3	15.1	15.2	14.7	14.4	15.3	9.7	10.5	26.7	28.2	24.4	23.4	4.3	4.9	11.4	9.7
Filling	15.6	14.6	14.6	16.2	14.7	15.1	14.6	17.0	2.4	1.9	4.5	4.9	13.2	14.3	7.4	10.2
Crimp Balance	1.09	+1.03	+1.04	1.10	1.02	+1.01	1.51	1.62	+11.3	+14.8	+5.42	+4.78	3.06	2.91	1.54	1.05
Threads/Load Drop [3]																
Warp	1.55	1.13	1.60	1.12	1.59	1.09	1.44	1.06	2.28	1.73	2.46	1.73	3.55	1.36	....	1.46
Filling	1.47	1.10	1.60	1.08	1.50	1.10	1.50	1.08	1.41	1.00	1.92	1.06	1.71	1.00	....	1.00

[1] 3″ Gage length in fabric.
[2] 10″ Gage length—Single yarn test.
[3] Number of peaks per inch of tear divided by number of threads per inch orthogonal to direction of tear.
[4] T.T.—Tail Tear.
[5] S.T.—Side Tear.

fore will be examined in its relation to its immediate predecessor. To facilitate these discussions a tabulation has been prepared that contains a listing of three values, pertinent to the subject matter, which have been calculated from the data in Table 10 of the Appendix. These data found in Table 2 are, as follows:

1. **Absolute Change (lbs.)**—algebraic difference in $\overline{P}_u$, between two successive stages of production, (+) sign indicates that the later stage of production has a greater average upper peak load than the one preceding it.

2. **Relative Change (%)**—the absolute change in $\overline{P}_u$ expressed as a percentage of the $\overline{P}_u$ of the earlier stage of production.

3. **Total Change (%)**—is the difference between the $\overline{P}_u$ at any stage in production and the $\overline{P}_u$ of the greige fabric expressed as a percentage of the $\overline{P}_u$ of the greige fabric.

A pictorial representation of the Percent Relative Change data is found in Figure 4. There the effect on tear strength of each of the finishing operations is depicted by histograms which indicate the magnitude of the Percent Relative Change and also whether the tear strength was improved or impaired.

Before the actual discussion of the observed effects on tear strength of the various finishing treatments is begun, a qualifying remark must be made regarding the comments which will follow relative to the possible causes for these effects. It is not within the scope of the research outlined in Part I to delineate the causes for all of the observed effects. Certain potential causes for some of the results noted are suggested by the data and these will be brought out in the discussion; but it should be understood that they are only considered as potential causes and have not been shown to be such in actuality. A more detailed analysis of the causes will be undertaken in the second phase report covering the work in Part II of the subject contract.

EFFECT OF FINISHING TREATMENTS ON TEAR STRENGTH OF FABRIC AS RECEIVED FROM PRECEDING OPERATION

The Effect of Desizing

It is not surprising to note that desizing adversely affected the warpwise tear strength while it had only a minor effect on the fillingwise tear. This was for the most part a slight improvement. The deleterious effect on the warpwise tear strength was not a general result. Four of the samples were found to have between 20 and 26 percent loss in tear, two samples exhibited a slight improvement in tear, and the others did not yield any test data since either the greige or desized sample tore in the opposite direction. A comparison of the physical properties of the greige and the desized fabric samples is found in Table 3. A possible explanation for the loss in warpwise tear is suggested by the single end yarn strength data obtained from yarns removed from the fabrics and tested at 10-inch gage length. These data show that the desized warp yarns have lost an appreciable amount of tensile strength, whereas the filling yarns removed from the samples did not.

The Effect of Scouring (Class B vs C)

Following the scouring operation, the cotton fabrics all suffered the most severe losses in tear strength encountered after a single finishing treatment. This condition was found in both the warp and filling tear tests. It is very clearly demonstrated by the data in Table 2 and forcibly illustrated in Figure 4. The magnitude of these losses in tear strength, which are all 35% and up, is even more striking when one considers the data found in Table 4, which show that the fabric and yarn strength characteristics of the scoured goods are generally equivalent to and often superior to those of the desized samples. An examination of the other physical properties listed in Table 4 will show that the desized samples and the scoured samples do not differ appreciably in ends and picks per inch, weight, percent crimp, or crimp balance. The most significant change in a fabric property following the scouring operation is found in the number of threads breaking per load drop during the tearing operation.

Table 5.—*Comparison of physical properties of the scoured (C) and bleached & dyed fabrics (D)*

Sample Classification	1 C	vs D	2 C	vs D	3 C	vs D	4 C	vs D	5 C	vs D	6 C	vs D	7 C	vs D	8 C	vs D
$\bar{P}_u$ - Warp	1.74	1.65	1.87	1.58	1.79	1.51	3.09	1.44	2.54	2.29	1.97	1.87	5.65	5.12	S.T.[4]	6.47
Filling	1.37	1.44	1.38	1.53	1.30	1.38	2.96	1.70	2.39	2.59	1.35	1.40	4.07	4.93	3.90	4.57
Ends/Inch	86	93	86	93	85	93	89	88	145	143	138	142	135	1.35	114	116
Picks/Inch	85	72	85	75	88	76	91	82	61	51	80	67	55	54	56	55
Weight (oz/yd²)	3.74	3.38	3.61	3.50	3.60	3.47	3.58	3.16	4.78	3.99	3.72	3.14	6.41	6.24	7.99	8.22
Ravel Strip Tensile																
(lbs.) - Warp	55.0	61.6	56.2	65.4	53.5	61.8	43.8	51.2	90.3	117.2	72.8	81.5	142.8	138.4	178.2	181.4
Filling	46.0	36.8	47.2	41.9	39.9	34.2	63.8	50.2	68.4	66.6	51.8	42.3	70.8	68.0	79.1	88.2
% Elong. Warp	24.6	6.99	25.3	8.13	25.1	8.1	19.7	6.5	41.7	12.4	38.8	11.1	14.0	9.7	18.3	16.5
Filling	27.7	36.2	25.9	36.5	26.3	33.6	27.8	25.2	11.0	9.6	12.3	14.4	22.3	19.7	16.7	18.4
Yarn Strength																
IN[1] - Warp	0.64	0.66	0.65	0.70	0.63	0.66	0.52	0.58	0.62	0.82	0.53	0.57	1.06	1.02	1.56	1.56
Filling	0.54	0.51	0.56	0.56	0.45	0.45	0.70	0.61	1.12	1.31	0.65	0.63	1.29	1.26	1.41	1.60
OUT[2] - Warp	0.52	0.66	0.64	0.64	0.61	0.64	0.54	0.57	0.65	0.64	0.54	0.54	0.88	0.84	1.44	1.42
Filling	0.51	0.44	0.48	0.49	0.39	0.46	0.63	0.59	1.21	1.29	0.61	0.53	1.28	1.32	1.43	1.62
% Crimp - Warp	15.1	0.7	14.7	1.8	15.3	1.9	10.5	1.3	28.2	6.5	23.4	5.1	4.9	2.6	9.7	9.0
Filling	14.6	24.9	16.2	25.4	15.1	22.9	17.0	17.2	1.9	3.2	4.9	8.2	14.3	12.4	10.2	10.9
Crimp Balance	+1.03	35.6	1.10	14.1	+1.01	12.05	1.62	13.2	+14.8	+2.03	+4.78	1.61	2.91	4.77	1.05	1.21
Threads/Load Drop[3]																
Warp	1.13	1.39	1.12	1.48	1.09	1.43	1.06	1.18	1.73	1.58	1.73	1.51	1.36	1.85	1.46	1.62
Filling	1.10	1.38	1.08	1.48	1.10	1.38	1.08	1.18	1.00	1.04	1.06	1.02	1.00	1.35	1.00	1.14

[1] 3-inch gage length in fabric.
[2] 10-inch gage length—single yarn test.
[3] Number of peaks per inch of tear divided by number of threads per inch orthogonal to direction of tear.
[4] S.T.—side tear.

Here it is seen that a sharp decrease in the average number of threads breaking per load drop is evidenced by the scoured samples. Since the number of threads per load drop is usually an excellent indication of the relative number of yarns in the del (See Figure 2), and in the fabric acting in parallel with the del, that are supporting the load imposed on the sample during the tearing action, it does not appear unreasonable to conclude that the change noted in this property is the principal cause of the losses in tear strength exhibited by all the samples after the scouring operation. This is not a surprising result since it is the purpose of the scour to remove the cotton waxes and other impurities which are the natural lubricants of the surface of the cotton fibers. Lacking this lubricity it is reasonable to assume that the friction and other restraints between yarns at the cross-overs will increase, thereby curtailing the mobility of the yarns in the fabric. Thus the number of yarns moving into the del to support the tear load would be decreased and the average upper peak load would be adversely affected.

The Effect of Bleaching and Dyeing (Class C vs D)

Only minor changes in tear characteristics were noted in the sample fabrics after the bleaching and dyeing operations. At this stage of production the fabrics are ready for resin treatment and are referred to herein as the "prepared" goods. It is interesting to note that as in the case of the desized samples, the "prepared" goods lost strength in the warp direction and gained it in the filling direction. Granted the changes are not as large as those observed after the previous operations, but an examination of Figure 4 shows that they are consistent, at least in direction, among the variety of samples investigated. Thus the statement can be made that there does exist a trend towards better fillingwise tear and poorer warpwise tear following the bleaching and dyeing operations. The data in Table 5 on percent crimp and crimp balance appear to offer some explanation for this trend. It will be noted that in almost every case the crimp in the warp yarns of the "prepared" fabrics is drastically lower than that of the scoured goods and the filling crimp is appreciably higher. Earlier work on the mechanics of tear has indicated that it is not unreasonable to expect that a fabric with higher crimp in the yarns being torn, which is able thereby to effect an increase in the ratio of the length of the del to its width, will have somewhat better resistance to tear. These results seem to confirm this hypothesis.

The Effect of Resin Treatment (Class D vs. E)

Table 2 and Figure 4 contain the data which describe the change in tear strength characteristics exhibited by the sample fabrics after resin treatment. It is readily apparent that resin treatment did not result in a consistent trend in its effect on tear. Warpwise, the magnitude of the percentage change in tear due to resinating was moderate, and increases as well as decreases in tear strength were noted. Fillingwise, the resin treatment seems to have been more severe in its effect on tear with half the samples manifesting a loss of approximately 30%. As in the case of the warpwise tear results, some fillingwise tear test indicated that resinating had significantly improved the tear strength of the cotton fabrics.

Thus it can be seen that the effect of resin treatment on cotton fabrics is difficult to define. It is complex in its mechanism, inconsistent in its result, and it is virtually impossible to isolate and distinguish it from the effects of the preceding processes. A detailed empirical and theoretical study will be made of the effects of resin treatment on tear strength in our Phase Report Number 2 which will cover the requirements of Part II of the subject contract. However, it is possible to offer some broad statements at this time, about the behavior of the fabrics which manifested more than a 10% relative change in resistance to tear after resin treatment. It should be understood that the percent relative change referred to above is based on the level of tear strength found in the "prepared" goods.

An examination of Figure 4 will reveal that five of the sample fabrics exhibited losses in either warp or filling tear (sometimes in both) in the order of 10% or more, while four fabrics exhibited more than 10% improvement in tear strength in the resin treated state. A comparison of the physical properties of the "prepared" goods and the resin-treated fabrics is found in Table 6.

Table 6.—*Comparison of physical properties of "prepared" goods (D) and resin treated fabrics (E)*

Sample Classification	1 D	1 E	2 D	2 E	3 D	3 E	4 D	4 E	5 D	5 E
$\overline{P}_u$ - Warp	1.65	1.87	1.58	1.46	1.51	1.28	1.44	1.68	2.29	2.92
Filling	1.44	1.72	1.53	1.00	1.38	0.89	1.70	1.62	2.59	-----
Ends/Inch	93	85	93	85	93	85	88	81	143	143
Picks/Inch	72	76	75	80	76	74	82	83	51	51
Weight (oz/yd²)	3.38	3.29	3.50	3.77	3.47	3.19	3.16	3.23	3.99	4.31
Ravel Strip Tensile										
(lbs.) - Warp	61.6	52.8	65.4	42.8	61.8	39.9	51.2	37.3	117.2	93.7
Filling	36.8	33.1	41.9	25.1	34.2	20.6	50.2	37.4	66.6	53.3
% Elong. Warp	6.99	8.24	8.13	10.8	8.1	6.4	6.5	4.9	12.4	9.9
Filling	36.2	24.7	36.5	18.4	33.6	15.7	25.2	12.4	9.6	5.7
Yarn Strength										
IN[1] - Warp	0.66	0.62	0.70	0.50	0.66	0.47	0.58	0.46	0.82	0.66
Filling	0.51	0.44	0.56	0.31	0.45	0.28	0.61	0.45	1.31	1.05
OUT[2] Warp	0.66	0.54	0.64	0.44	0.64	0.42	0.57	0.39	0.64	0.51
Filling	0.44	0.38	0.49	0.30	0.46	0.22	0.59	0.32	1.29	1.01
% Crimp - Warp	0.7	1.9	1.8	6.3	1.9	2.4	1.3	2.3	6.5	8.4
Filling	24.9	14.3	25.4	14.0	22.9	10.7	17.2	9.1	3.2	1.9
Crimp Balance	35.6	7.53	14.1	2.22	12.05	4.46	13.2	3.96	+2.03	+4.42
Threads/Load Drop[3]										
Warp	1.39	1.56	1.48	1.57	1.43	1.66	1.18	1.54	1.58	1.82
Filling	1.38	1.40	1.48	1.54	1.38	1.31	1.18	1.41	1.04	-----
$\overline{P}_u$ - Warp	1.87	D.T.[4]	5.12	S.T.[5]	6.47	S.T.[5]	T.T.[6]	S.T.[5]	T.T.[6]	S.T.[5]
Filling	1.40	1.96	4.93	3.63	4.57	3.30	11.26	6.16	T.T.	S.T.
Ends/Inch	142	139	135	130	116	116	51	54	59	61
Picks/Inch	67	69	54	54	55	55	50	49	54	53
Weight (oz/yd²)	3.14	3.30	6.24	6.35	8.22	8.31	2.92	3.99	4.55	4.96
Ravel Strip Tensile										
(lbs.) - Warp	81.5	68.2	138.4	114.0	181.4	132.8	70.9	78.3	55.5	59.2
Filling	42.3	32.4	68.0	46.1	88.2	52.1	49.2	47.9	55.2	49.0
% Elong. - Warp	11.1	10.2	9.7	7.5	16.5	12.4	8.5	6.0	8.0	4.7
Filling	14.4	10.4	19.7	15.5	18.4	12.3	6.1	5.7	7.2	5.6
Yarn Strength										
IN[1] - Warp	0.57	0.49	1.02	0.88	1.56	1.14	1.39	1.45	0.94	0.97
Filling	0.63	0.47	1.26	0.85	1.60	0.95	0.98	0.98	1.02	0.92
OUT[2] - Warp	0.54	0.42	0.84	0.71	1.42	0.99	1.40	1.39	1.14	1.21
Filling	0.53	0.41	1.32	0.79	1.62	0.92	1.00	0.96	1.20	0.95
% Crimp - Warp	5.1	7.0	2.6	2.6	9.0	7.5	7.9	4.2	7.8	3.3
Filling	8.2	5.9	12.4	10.3	10.9	8.1	4.3	9.1	5.3	9.1
Crimp Balance	1.61	+1.19	4.77	3.91	1.21	1.08	1.84	2.17	1.47	2.76
Threads/Load Drop[3]										
Warp	1.51	------	1.85	------	1.62	------	------	------	------	------
Filling	1.02	1.46	1.35	1.36	1.14	1.35	1.54	1.20	------	------

[1] 3-inch gage length in fabric.
[2] 10-inch gage length—single yarn test.
[3] Number of peaks per inch of tear divided by number of threads per inch orthogonal to direction of tear.
[4] D. T.—diagonal tear.
[5] S. T.—side tear.
[6] T.T.—tail tear.

Table 7.—*Comparison of some physical properties of samples manifesting more than 10% relative change in tear strength after resin treatment*

Sample Number	Test Specimen	% Change in Tear	Yarn Strength IN D	Yarn Strength IN E	Yarn Strength OUT[1] D	Yarn Strength OUT[1] E	Threads/Peak D	Threads/Peak E	Percent Change Yarn Strength IN	Percent Change Yarn Strength OUT	Percent Change Threads/Peak
A. Samples Exhibiting Loss in Tear Strength:											
2	F	34.5	.56	.31	.49	.30	1.48	1.54	—44.6	—38.8	+4.1
3	W	15.2	.66	.47	.64	.42	1.43	1.66	—28.8	—34.4	+16.1
	F	35.5	.45	.28	.42	.22	1.38	1.31	—37.8	—52.2	—5.1
7	F	26.4	1.26	.85	1.32	.79	1.35	1.36	—32.5	—40.1	+0.7
8	F	27.8	1.60	.95	1.62	.92	1.14	1.35	—40.6	—43.2	+18.4
9	F	45.8	.98	.98	1.00	.96	1.54	1.20	0	—4.0	—22.1
					Average % Change				—31%	—35.4%	+2.0%
B. Samples Exhibiting Increase in Tear Strength:											
1	W	13.3	.66	.62	.66	.44	1.39	1.56	—6.1	—18.2	+12.2
	F	19.4	.51	.44	.44	.38	1.38	1.40	—13.7	—13.6	+1.4
4	W	16.7	.58	.46	.57	.39	1.18	1.54	—20.7	—31.6	+30.5
5	W	27.5	.82	.66	1.31	1.05	1.58	1.82	—19.5	—19.7	+15.3
6	F	40.0	.63	.47	.53	.41	1.02	1.46	—25.4	—22.7	+43.1
					Average % Change				—17%	—21.2%	+20.5%

[1] OUT—yarn removed from fabric, tested at 10 inch gage length.

Table 8.—*A comparison of the total percent loss in tear strength*[1] *after the scouring and resinating operations considering the tear strength of the greige fabric as the base value*

Sample Number	Absolute Loss in Strength (lbs.) Warp After Scour	Absolute Loss Warp After Resin	Absolute Loss Filling After Scour	Absolute Loss Filling After Resin	Relative Loss in Strength (%) Warp After Scour	Relative Loss Warp After Resin	Relative Loss Filling After Scour	Relative Loss Filling After Resin
1	—2.26	—2.13	0.74	0.39	56.5	53.3	35.0	18.4
2	2.09	2.50	0.81	1.19	52.8	63.1	37.0	54.4
3	2.00	2.51	0.73	1.14	52.8	66.3	36.0	56.2
4	1.73	1.41	1.24	1.34	56.0	45.6	42.0	45.3
5	2.30	1.92	3.18	X[3]	47.6	39.6	57.0	X
6	2.59	X	1.09	0.48	59.5	X	44.7	19.7
7	[2] 3.28	S.T.[4]	1.33	1.77	36.7	S.T.	24.6	32.8
8	S.T.	S.T.	1.74	2.34	S.T.	S.T.	30.9	41.5
			Average % loss		51.7	53.6	38.4	38.3

[1] Using strength of greige goods as base value.
[2] Strength of desized sample used as base value.
[3] X—tore diagonally.
[4] S.T.—side tear.

Table 9.—*Comparison of physical properties of "prepared" goods (D) and nonresinated finished fabric (F)*

Sample Classification	1 D	vs F	2 D	vs F	3 D	vs F	4 D	vs F	5 D	vs F	6 D	vs F	7 D	vs F
$\bar{P}_u$ - Warp	1.65	1.56	1.58	1.60	1.51	1.48	1.44	1.43	2.29	2.33	5.12	7.63	6.47	S.T.[4]
Filling	1.44	1.60	1.53	1.48	1.38	1.60	1.70	1.64	2.59	2.61	4.93	6.22	4.57	6.28
Ends/Inch	93	85	93	87	93	86	88	83	143	144	135	129	116	112
Picks/Inch	72	73	75	76	76	74	82	83	51	51	54	53	55	54
Weight (oz/yd^2)	3.38	3.15	3.50	3.24	3.47	3.15	3.16	3.04	3.99	3.99	6.24	6.07	8.22	7.68
Ravel Strip Tensile														
(lbs.) - Warp	61.6	56.1	65.4	60.3	61.8	51.4	51.2	51.0	117.2	111.6	138.4	128.4	181.4	164.4
Filling	36.8	38.7	41.9	43.5	34.2	35.0	50.2	52.2	66.6	67.2	68.0	71.5	88.2	83.8
% Elong. - Warp	6.99	8.48	8.13	9.68	8.1	7.6	6.5	7.0	12.4	12.4	9.7	10.4	16.5	15.9
Filling	36.2	25.3	36.5	25.0	33.6	22.0	25.2	19.7	9.6	8.6	19.7	16.0	18.4	14.0
Yarn Strength														
IN[1] - Warp	0.66	0.66	0.70	0.69	0.66	0.60	0.58	0.58	0.82	0.78	1.02	1.00	1.56	1.47
Filling	0.51	0.53	0.56	0.57	0.45	0.47	0.61	0.61	1.31	1.32	1.26	1.34	1.60	1.55
OUT[2] - Warp	0.66	0.65	0.64	0.74	0.64	0.55	0.57	0.50	0.64	0.68	0.84	0.91	1.42	1.42
Filling	0.44	0.46	0.49	0.45	0.46	0.46	0.59	0.59	1.29	1.21	1.32	1.23	1.62	1.37
% Crimp - Warp	0.7	1.4	1.8	2.0	1.9	2.5	1.3	2.3	6.5	7.3	2.6	2.7	9.0	8.1
Filling	24.9	15.4	25.4	16.9	22.9	15.1	17.2	12.4	3.2	2.1	12.4	8.5	10.9	7.1
Crimp Balance	35.6	11.0	14.1	8.45	12.05	6.04	13.2	5.39	+2.03	+3.48	4.77	3.15	1.21	1.14
Threads/Load Drop[3]														
Warp	1.39	1.30	1.48	1.38	1.43	1.24	1.18	1.10	1.58	1.60	1.85	1.80	1.62	------
Filling	1.38	1.46	1.48	1.36	1.38	1.24	1.18	1.16	1.04	1.01	1.35	1.29	1.14	1.45

[1] 3-inch gage length in fabric.
[2] 10-inch gage length—single yarn test.
[3] Number of peaks per inch of tear divided by number of threads per inch orthogonal to direction of tear.
[4] S.T.—side tear.

In general, those fabrics exhibiting the most severe decreases in yarn strength suffered losses in tear strength. On the average the percent loss in yarn strength found in these fabrics was approximately double that of the fabrics which had improved tear strength after resin treatment. Another point to be considered is that these fabrics did not exhibit any appreciable change in the number of threads breaking per load drop during the tearing operation. It is, therefore, quite reasonable to expect that a resin-treated fabric, with less yarn strength and approximately the same number of yarns supporting the load as the "prepared" goods, will have a lower average upper peak load than that of the "prepared" goods. In one sample (Number 9—filling) despite no loss in yarn strength, the fabric was found to have 45% less tear strength after resin treatment. This fabric exhibited a sharp decrease in the number of threads per load drop which probably accounts for a major part of its loss in tear.

As mentioned above, the samples that were found to possess improved tear characteristics after resinating did not suffer the same extent of damage in yarn strength as the other fabrics. They did, however, exhibit a greater degree of yarn mobility in the fabric as evidenced by the increase in the number of threads breaking per load drop.

A comparison of the yarn strength ("IN" and "OUT") and threads per peak data for Class D and E samples, which exhibited more than a 10% relative change tear, is shown in Table 7.

An interesting comparison of the losses in tear strength after the scouring and resinating operations, considering the tear resistance of the greige fabric as the base value, is found in Table 8. The average percentage loss in tear strength is the same after scouring as it is following the resinating operation. Fillingwise, the loss is not as great as that in the warp tests; however, in view of the variability among the samples, the significance of this difference is questionable.

This equivalence in the magnitude of the total percent loss in tear observed in the scoured and resin-treated samples does not mean that scouring, which precedes resin treatment, is the sole cause of the loss in tear strength found in the resin-treated samples. Undoubtedly, it contributed to it but the extent of this contribution is not easily determined.

Effect of Changes in Texture and Crimp Balance (Class D vs. F)

To evaluate the effect of changes in fabric geometry, i.e., ends and picks per inch, percent crimp, and crimp balance, a comparison was made of the tear strength of the "prepared" goods with that of the sample framed to the same construction as the resin-finished goods, but without any resin—Class B versus F. In general, there was very little difference found in the tear strength characteristics of the sample in Class D and F; but there were several fabrics that exhibited a great improvement in tear strength when the "prepared" goods were framed out to approximate the construction of the finished fabric, and the resin was omitted. None of the samples appeared significantly weaker as a result of this handling.

Table 9 presents a comparison of the pertinent physical properties for all the samples available in these two classifications. In Figure 4 it can be readily seen that only four sample fabrics were found to possess greater than a 10% improvement in tear between Class D and F. Of these four fabrics only one (Number 7) manifested a significant improvement in both warpwise and fillingwise tear strength, the others were all found to have significant increases in fillingwise tear and no real changes in warp tear.

There is no common denominator available that will explain the increase in resistance to tearing found in Samples 1, 3, 7, and 8. Samples 1 and 8 have more threads breaking per load drop in Class F, which could certainly account for a portion of the improved tear performance. Samples 3 and 7 have somewhat more open textures in the non-resinated finished fabric state (Class F) which is conducive to better tear resistance.

History of $\overline{P}_u$ From Greige to Finished Resin-Treated Fabric

To complement the above discussion, which was concerned with the effect of each finishing treatment on the tear strength of the fabric as received from the preceding operation, a series of graphs illustrates the absolute change in the measured average upper peak load at each step in the finishing sequence. (Figure 5).

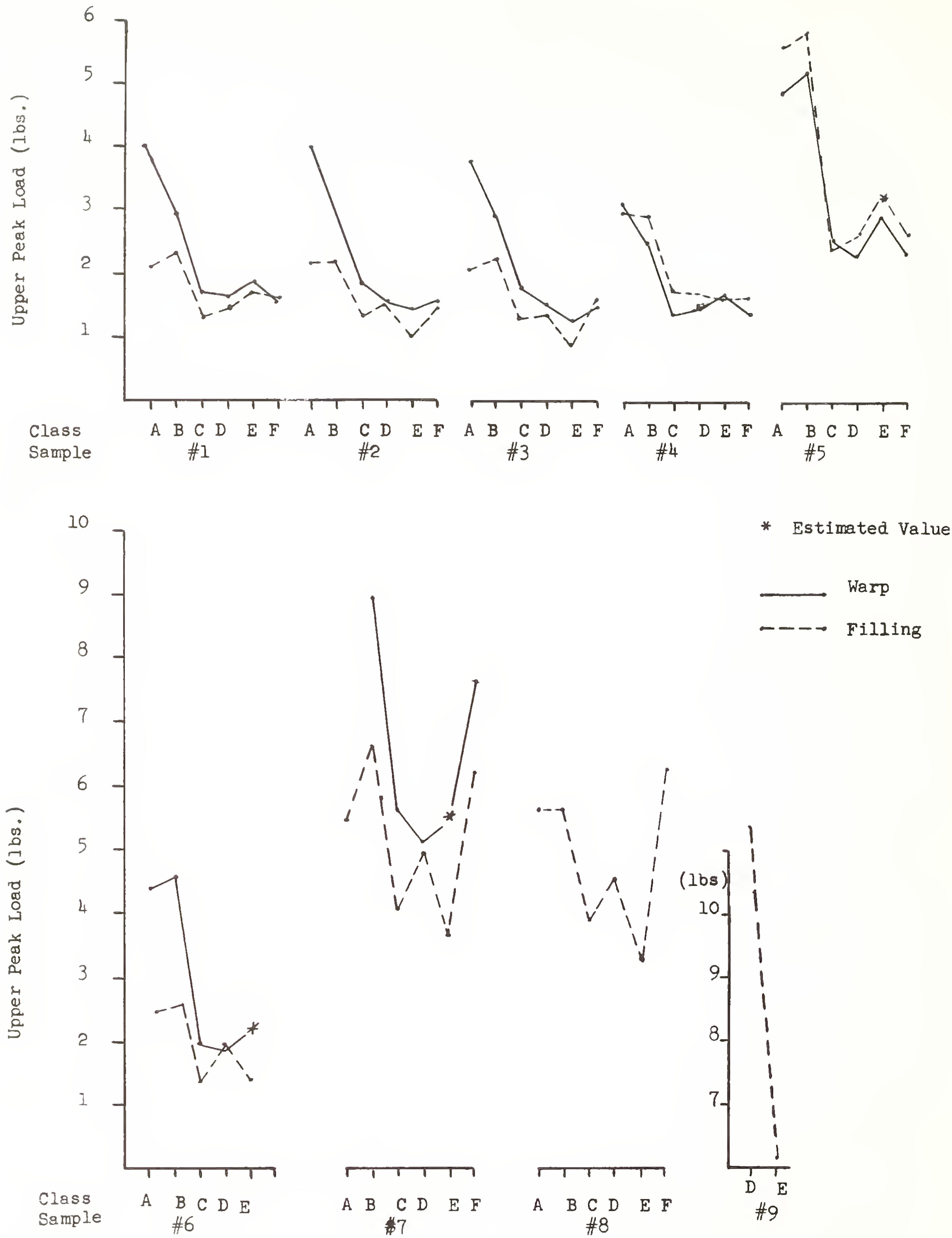

Figure 5.—*Effect of manufacturing processes on tear strength.*

In general these graphs depict a rapid loss in strength during the initial finishing treatments and only minor fluctuations in the subsequent stages. Samples 7 and 8, however, exhibit the large increase in tear, in the Class F stage, discussed on page 40.

The most significant point brought out by these data and their graphic counterpart is that the losses in tear strength, suffered by cotton fabrics during the finishing treatments, are generally more severe following the initial treatments than they are after the final treatments. It would seem appropriate, therefore, to direct some of the work in Part II to investigation of means to restore the tear strength of the cotton to some level approaching that observed in the greige state before the resin treatment is applied.

CONCLUSIONS

Based on the work performed in Part I of the subject contract and reported herein, the following conclusions appear reasonable:

1. Effect of handling during manufacturing processes.
   a. Desizing had a more deleterious effect on warp tear than on the fillingwise tear.
   b. Scouring resulted in the most severe losses in tear strength, both in the warp and filling directions.
   c. Bleaching and dyeing operations resulted in minor changes in tear strength, with warp tear generally decreasing while the fillingwise tear was slightly improved.
   d. After resin treatment one group of fabric exhibited large losses in resistance to tear while another group was found to have appreciably better tear strength.
   e. In several instances changes in fabric geometry, aimed at simulating the construction of the finished fabric, resulted in significant improvements in tear strength.
2. Change in tear strength between "prepared" state and resin-treated finished fabric.
   a. The fabrics that lost more than 10% of their tear strength exhibited large losses in yarn strength and very little change in the number of threads breaking per load drop. In one case, a fabric that did not lose any yarn strength, but still suffered a 45% loss in tear strength was found to have appreciably fewer threads breaking per load drop in the resin-treated fabric than in the "prepared" goods.
   b. Fabrics manifesting more than 10% improvement in tear following resin treatment generally evidenced an increase in the number of threads per peak. Thus the number of yarns supporting the load, both in the del and acting in parallel with it, must be significantly greater than those in the "prepared" goods, to result in an increase in tear strength despite an appreciable loss in yarn tensile strength.

Table 10.—*Summary of tongue-tear test data*

Sample Number	Across the warp yarns				Across the filling yarns			
	Upper peak load (lbs.)	Lower peak load (lbs.)	Tear energy (in-lbs.)	Tear force (lbs.)	Upper peak load (lbs.)	Lower peak load (lbs.)	Tear energy (in-lbs.)	Tear force (lbs.)
1-A [1]	4.00	2.86	......	......	2.11	1.38	3.84	1.76
B	2.94	2.16	6.14	2.64	2.33	1.72	4.68	2.05
C	1.74	1.13	3.54	1.55	1.37	0.86	2.63	1.17
D	1.65	1.07	3.28	1.38	1.44	0.76	2.33	1.08
E	1.87	1.21	3.68	1.64	1.72	1.15	2.89	1.43
F	1.56	1.04	3.16	1.39	1.60	0.82	2.56	1.24
2-A	3.96	2.88	7.76	3.57	2.19	1.51	3.97	1.87
B	2.98	2.14	6.15	2.63	2.17	1.52	4.41	1.93
C	1.87	1.23	3.83	1.66	1.38	0.84	2.72	1.20
D	1.58	1.09	3.40	1.43	1.53	0.78	2.44	1.19
E	1.46	0.95	2.95	1.29	1.00	0.65	1.75	0.85
F	1.60	1.08	3.19	1.42	1.48	0.73	2.27	1.11
3-A	3.79	2.60	7.45	3.42	2.03	1.38	3.71	1.73
B	2.92	2.09	5.91	2.54	2.24	1.56	4.48	1.95
C	1.79	1.16	3.63	1.57	1.30	0.82	2.54	1.13
D	1.51	1.04	3.27	1.36	1.38	0.75	2.20	1.09
E	1.28	0.82	2.41	1.13	0.89	0.54	1.47	0.72
F	1.48	1.00	3.04	1.31	1.60	0.98	2.80	1.33
4-A	3.09	2.30	5.88	2.76	2.96	2.28	5.69	2.67
B	2.45	1.86	4.99	2.17	2.90	2.14	5.72	2.54
C	1.36	0.88	2.70	1.19	1.72	1.11	3.32	1.48
D	1.44	0.96	2.86	1.25	1.70	1.05	3.01	1.46
E	1.68	1.23	3.18	1.47	1.62	1.18	2.87	1.42
F	1.43	0.95	2.70	1.26	1.64	1.01	2.82	1.37
5-A	4.84	4.20	9.61	4.69	5.57	4.67	10.95	5.12
B	5.18	4.56	10.47	4.94	5.84	4.70	12.81	5.23
C	2.54	1.82	4.79	2.30	2.39	1.55	4.76	2.06
D	2.29	1.67	4.42	2.08	2.59	1.60	4.44	2.18
E	2.92	2.42	5.76	2.82		Tore Diagonally		
F	2.33	1.71	4.53	2.12	2.61	1.59	4.64	2.24
6-A	4.36	3.65	8.74	4.10	2.44	1.87	4.60	4.10
B	4.56	3.72	9.22	4.28	2.53	1.87	5.20	2.24
C	1.97	1.28	3.65	1.72	1.35	0.87	2.67	1.18
D	1.87	1.28	3.68	1.68	1.40	0.76	2.29	1.13
E		Tore Diagonally			1.96	1.42	3.48	1.71
7-A		Side Tear			5.40	4.34	9.93	4.81
B	[2] 8.93	6.53	20.17	8.20	6.60	5.56	12.72	6.12
C	5.65	4.26	11.73	5.13	4.07	2.46	7.05	3.46
D	[2] 5.12	3.78	10.87	4.75	4.93	3.19	8.23	4.08
E		Side Tear			3.63	2.66	6.24	3.12
F	[3] 7.63	5.78	16.00	6.83	6.22	4.49	11.04	5.23
8-A		Side Tear			5.64	4.13	10.61	4.90
B		Tail Tear			5.65	4.56	10.72	5.12
C		Side Tear			3.90	2.48	6.83	3.31
D	6.47	4.63	13.57	5.84	4.57	2.91	8.31	3.98
E		Side Tear			3.30	2.20	5.87	2.82
F		Side Tear			6.28	3.97	10.93	5.28
9-D		Tail Tear			11.26	9.96	22.24	10.62
E		Side Tear			6.16	5.00	12.04	5.53
10-D		Tail Tear				Tail Tear		
E		Side Tear				Side Tear		

[1] A = greige goods.
B = desized.
C = desized and scoured.
D = desized, scoured, bleached and dyed
E = finished resin treated fabric
F = same construction as "E" without resin treatment

[2] Average of three tests.

[3] Average of four tests.

Table 11.—*Summary of fabric construction data*

Sample Number	Fabric weight (oz/sq.yd.)	Threads/Inch		Percent Crimp		Crimp [1] Balance
		Warp	Filling	Warp	Filling	
1-A	3.73	79	78	8.9	7.7	+1.16
B	3.77	85	84	14.3	15.6	1.09
C	3.74	86	85	15.1	14.6	+1.03
D	3.38	93	72	0.7	24.9	35.57
E	3.29	85	76	1.9	14.3	7.53
F	3.15	85	73	1.4	15.4	11.00
2-A	3.72	78	79	8.9	7.4	+1.20
B	3.83	84	84	15.2	14.6	+1.04
C	3.61	86	85	14.7	16.2	1.10
D	3.50	93	75	1.8	25.4	14.11
E	3.77	85	80	6.3	14.0	2.22
F	3.24	87	76	2.0	16.9	8.45
3-A	4.03	79	79	9.1	6.9	+1.32
B	3.73	85	84	14.4	14.7	1.02
C	3.60	85	88	15.3	15.1	+1.01
D	3.47	93	76	1.9	22.9	12.05
E	3.19	85	74	2.4	10.7	4.46
F	3.15	86	74	2.5	15.1	6.04
4-A	3.41	79	86	5.2	8.1	1.56
B	3.53	84	89	9.7	14.6	1.51
C	3.58	84	91	10.5	17.0	1.62
D	3.16	88	82	1.3	17.2	13.23
E	3.23	81	83	2.3	9.1	3.96
F	3.04	83	83	2.3	12.4	5.39
5-A	4.70	142	53	13.9	0.7	+19.85
B	4.90	144	60	26.7	2.4	+11.13
C	4.78	145	61	28.2	1.9	+14.84
D	3.99	143	51	6.5	3.2	+2.03
E	4.31	143	51	8.4	1.9	+4.42
F	3.99	144	51	7.3	2.1	+3.48
6-A	3.75	135	70	10.0	3.2	+3.13
B	3.86	137	79	24.4	4.5	+5.42
C	3.72	138	80	23.4	4.9	+4.78
D	3.14	142	67	5.1	8.2	1.61
E	3.30	139	69	7.0	5.9	+1.19
7-A	7.25	125	55	6.2	5.1	1.22
B	6.73	135	55	4.3	13.2	3.06
C	6.41	135	55	4.9	14.3	2.91
D	6.24	135	54	2.6	12.4	4.77
E	6.35	130	54	2.6	10.3	3.96
F	6.07	129	53	2.7	8.5	3.15
8-A	9.26	110	57	13.3	4.4	3.02
B	8.36	112	56	11.4	7.4	1.54
C	7.99	114	56	9.7	10.2	1.05
D	8.22	116	55	9.0	10.9	1.21
E	8.31	116	55	7.5	8.1	1.08
F	7.68	112	54	8.1	7.1	1.14
9-D	2.92	51	50	7.9	4.3	1.84
E	3.99	54	49	4.2	9.1	2.17
10-D	4.55	59	54	7.8	5.3	1.47
E	4.96	61	53	3.3	9.1	2.76

[1] Crimp balance is the ratio of the highest to the lowest crimp. A (+) prefix denotes greater warp than filling crimp while the absence of a prefix signifies that the filling crimp is larger than the warp crimp.

Table 12.—*Summary of fabric tensile strength data*

Sample Number	Ravel strip tensile (lbs.)		Elongation (pct.)	
	Warp	Filling	Warp	Filling
1-A	58.1	47.4	16.1	16.2
B	52.7	44.5	24.9	27.4
C	55.0	46.0	24.6	27.7
D	61.6	36.8	6.99	36.2
E	52.8	33.1	8.24	24.7
F	56.1	38.7	8.48	25.3
2-A	57.2	45.8	17.6	16.8
B	51.1	43.1	25.5	25.5
C	56.2	47.2	25.3	25.9
D	65.4	41.9	8.13	36.5
E	42.8	25.1	10.8	18.4
F	60.3	43.5	9.68	25.0
3-A	58.1	44.5	16.0	14.5
B	52.4	41.7	24.7	25.1
C	53.5	39.9	25.1	26.3
D	61.8	34.2	8.1	33.6
E	39.9	20.6	6.4	15.7
F	51.4	35.0	7.6	22.0
4-A	47.4	55.3	10.9	16.0
B	43.1	49.6	18.9	26.7
C	43.4	63.8	19.7	27.8
D	51.2	50.2	6.5	25.2
E	37.3	37.4	4.9	12.4
F	51.0	52.2	7.0	19.7
5-A	103.2	57.8	23.4	8.5
B	99.5	59.7	46.4	10.9
C	90.3	68.4	41.7	11.0
D	117.2	66.6	12.4	9.6
E	93.7	53.3	9.9	5.7
F	111.6	67.2	12.4	8.6
6-A	91.2	48.7	20.6	11.3
B	83.2	49.4	40.4	13.9
C	72.8	51.8	38.8	12.3
D	81.5	42.3	11.1	14.4
E	68.2	32.4	10.2	10.4
7-A	133.6	65.2	15.8	13.1
B	122.8	57.9	13.4	21.3
C	142.8	70.8	14.0	22.3
D	138.4	68.0	9.7	19.7
E	114.0	46.1	7.5	15.5
F	128.4	71.5	10.4	16.0
8-A	160.4	79.8	24.4	11.5
B	164.0	67.8	20.7	14.1
C	178.2	79.1	18.3	16.7
D	181.4	88.2	16.5	18.4
E	132.8	52.1	12.4	12.3
F	164.4	83.8	15.9	14.0
9-D	70.9	49.2	8.5	6.1
E	78.3	47.9	6.0	5.7
10-D	55.5	55.2	8.0	7.2
E	59.2	49.0	4.7	5.6

Table 13.—*Summary of yarn tensile strength data*

Sample Number	Warp			Filling		
	Out of Fabric		IN Fabric	Out of Fabric		IN Fabric
	10″ G.L.	0.5″ G.L.	3″ G.L.	10″ G.L.	0.5″ G.L.	3″ G.L.
1-A	.74	1.05	.74	.38	.55	.61
B	.65	------	.62	.45	----	.53
C	.52	------	.64	.51	----	.54
D	.66	.82	.66	.44	.65	.51
E	.54	.75	.62	.38	.48	.44
F	.65	.86	.66	.46	.62	.53
2-A	.71	.96	.73	.43	.53	.58
B	.60	----	.61	.42	----	.51
C	.64	----	.65	.48	----	.56
D	.64	.86	.70	.49	.60	.56
E	.44	.60	.50	.30	.37	.31
F	.74	.95	.69	.45	.66	.57
3-A	.69	.97	.74	.34	.48	.56
B	.55	----	.62	.42	----	.50
C	.61	----	.63	.39	----	.45
D	.64	.75	.66	.46	.59	.45
E	.42	.55	.47	.22	.31	.28
F	.55	.80	.60	.46	.58	.47
4-A	.56	.73	.60	.40	.50	.64
B	.45	----	.51	.40	----	.56
C	.54	----	.52	.63	----	.70
D	.57	.71	.58	.59	.76	.61
E	.39	.57	.46	.32	.42	.45
F	.50	.71	.58	.59	.76	.61
5-A	.63	.78	.73	.99	1.26	1.09
B	.56	----	.69	1.02	------	.99
C	.65	----	.62	1.21	------	1.12
D	.64	.94	.82	1.29	1.37	1.31
E	.51	.67	.66	1.01	1.17	1.05
F	.68	.91	.78	1.21	1.47	1.32
6-A	.57		.67	.49		.70
B	.50		.61	.56		.63
C	.54		.53	.61		.65
D	.54		.57	.53		.63
E	.42		.49	.41		.47
7-A	.92		1.07	1.02		1.18
B	.74		.91	1.04		1.05
C	.88		1.06	1.28		1.29
D	.84		1.02	1.32		1.26
E	.71		.88	.79		.85
F	.91		1.00	1.23		1.34
8-A	1.42		1.46	.94		1.40
B	1.17		1.46	1.10		1.21
C	1.44		1.56	1.43		1.41
D	1.42		1.56	1.62		1.60
E	.99		1.14	.92		.95
F	1.42		1.47	1.37		1.55
9-D	1.40		1.39	1.00		.98
E	1.39		1.45	.96		.98
10-D	1.14		.94	1.20		1.02
E	1.21		.97	.95		.92

Table 14.—*Summary of number of threads rupturing per load drops* [1]

Sample Number	Warp	Filling	Sample Number	Warp	Filling
1-A	1.74	1.62	6-A	1.99	1.65
B	1.55	1.47	B	2.46	1.92
C	1.13	1.10	C	1.73	1.06
D	1.39	1.38	D	1.51	1.02
E	1.56	1.40	E	[3] D. T.	1.46
F	1.30	1.46	7-A	[2] S.T.	1.63
2-A	1.54	1.59	B	3.55	1.71
B	1.60	1.60	C	1.36	1.00
C	1.12	1.08	D	1.85	1.35
D	1.48	1.48	E	S.T.	1.36
E	1.57	1.54	F	1.80	1.29
F	1.38	1.36	8-A	S.T.	1.44
3-A	1.62	1.44	B	T.T	1.46
B	1.59	1.50	C	S.T.	1.00
C	1.09	1.10	D	1.62	1.14
D	1.43	1.38	E	S.T.	1.35
E	1.66	1.31	F	S.T.	1.45
F	1.24	1.24	9-D	T.T.	1.54
4-A	1.58	1.56	E	S.T.	1.20
B	1.44	1.50			
C	1.06	1.08			
D	1.18	1.18	10-D	T.T.	T.T.
E	1.54	1.41	E	S.T.	S.T.
F	1.10	1.16			
5-A	1.93	1.26			
B	2.28	1.41			
C	1.73	1.00			
D	1.58	1.04			
E	1.82				
F	1.60	1.01			

[1] Obtained by dividing the number of threads per inch orthogonal to the direction of tear by the number of peaks (load drops) per inch of tear.

[2] Side tear.

[3] Diagonal tear.

[4] Tail tear.

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